Development of an Operational Approach for Mapping Mosquito Breeding Sites from Airborne Synthetic Aperture Radar

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Abstract: The research objective is to investigate the practical application of SAR imagery to identify the detailed pattern of flooding beneath the canopy of partially flooded mangrove forests. This is to facilitate modification of the environment for disease bearing mosquito control. The study area is in subtropical SE Queensland Australia (S27° 53`; E153$^{\circ}$ 20`). Fully polarimetric AIRSAR imagery was obtained in November 1996 (PACRIM mission) at a time when remnant water would be lying under the forest. The AIRSAR data were ground-range adjusted to a 5 x 5m resolution, georeferenced to a thermal image, and a subset extracted for detailed study. Data analysis used ENVI software. Single-band analysis indicated that P-Band was better at identifying pools than C or L-band with a reasonable pool alignment using P-band TP. Multi-band analysis is work in progress:

1. Unsupervised classification of P-band in HH, VV and HV resulted in the best discrimination of pools.
2. ENVI's AIRSAR Scattering Classification procedure differentiated individual scattering mechanisms. This provided some interesting and surprising results such as the P-band odd-bounce relationship with pools under canopy.
3. Principal Component Analysis of C-, L- and P- bands using HH, VV and HV produced a first component which explained about 80% of the variance, whereas the second component with 15% of the variance closely matched the pool perimeters.

These analyses are encouraging, but there remain issues to be resolved, including: limitations of the resolution (a 1m pixel would be ideal); range size distortions need to be addressed; scattering mechanisms and their influence on the identification of features need to be investigated; data accessibility and usability remains a challenge in interactive analysis programs. For example, the routines which use the raw stokes matrix as input and which output slant range images require a lengthy processing sequence to obtain standard reference and spatial dimensions. As well, there remains the need to collect appropriate ground data.

1. Aims

The aim of this project, which began in 1995, is to develop a robust approach for mapping the location of mangrove forest breeding sites of the disease bearing saltmarsh mosquito. It will develop methods applicable to current and next generation airborne and satellite radar imaging sensors that can be utilised in Australia and other countries. The study area is a major mosquito breeding mangrove forest in south east Queensland. There are three main objectives. These are to:

1. acquire synthetic aperture radar (SAR) image and field data at the same time,
2. identify relationships between biophysical characteristics of mangrove forest particularly flooding regime and responses in fully polarimetric SAR data,
3. determine the optimal SAR wavelength and polarisation combination that maximises the contrast between flooded and "dry" areas under forested canopies, and
4. develop and test a methodology for detailed mapping of the location of flooded areas.

This report presents progress to date in developing relationships between fully polarimetric, multifequency SAR data and the biophysical characteristics of the mangrove forest with respect to the flooding regime. The data were acquired during the 1996 AIRSAR campaign in the Pacific Rim area.

1. Background

Mosquitoes are a major human health hazard in both developed and developing countries. In Australia the salt marsh mosquito (*Aedes vigilax*) breeds in intertidal wetlands and is one of the major vectors of arbovirus diseases such as Ross River virus (RRv) (Russell 1993). The annual rate of RRv notification is reported to be increasing (Curran *et al*. 1997). A recent approach developed in Australia has been to design habitat modifications to manage mosquitoes, using natural hydrological patterns and interfering as little as possible in natural processes. For open saltmarshes, this method is called runnelling (Dale *et al*. 1986a, 1986b, 1993; Hulsman *et al*. 1989). This technique has been applied successfully throughout Australia and in parts of the U.S.A. (Dale *et al*. 1994). It relies on accurate identification of mosquito breeding pools and depressions within the salt marsh.

The concept of runnelling is applicable to other mosquito breeding habitats such as mangroves. Mosquito breeding under the mangrove canopy is in relatively shallow standing water bodies that persist for at least five days in summer after high tides (Dale *et al*. 1998a). An essential prerequisite to modifying the habitat is to accurately map the distribution of pools and channels. In open vegetation, aerial photography and field survey are simple sources of relevant information and much work on salt marshes has been completed by Dale (Dale *et al*. 1998b, 1996, Ritchie and Dale 1994). Under mangrove canopies field work is very difficult, time consuming and damaging to the environment. Remote sensing (RS) is a non-intrusive method of survey, and Dale *et al*. have used various forms of RS from aerial photography to airborne thermal scanner images to map potential mosquito breeding sites. All have provided some degree of success, but fall short of an optimum approach (Dale *et al*. 1998 a and b, 1996, Ritchie and Dale 1994). Both aerial photography and thermal image data are limited by the conditions they can operate under (clear sky) and that aerial photography, in particular, are measuring canopy attributes, when the mosquito breeding areas are located beneath the canopy. Thermal imagery measures heat radiating from and through the canopy.

Synthetic aperture radar (SAR) data have been applied to map flooded forests (Hess 1998, Milne *et al*. 1998, Kasischke *et al*. 1997, Hess and Melack 1994, Hess *et al*. 1990). However, none of these applications have focussed specifically on mangrove environments nor at a fine enough spatial scale to be able to provide the detail required to identify pools under the canopy, necessary for mapping potential mosquito breeding habitats. Limited attention has also been paid to utilising all of the information available in fully polarimetric SAR data sets, but where they have, mapping accuracy is maximised (Van Zyl and Burnette 1992).

2. Methods

Quantitative analyses of remotely sensed data requires contemporaneous field and image data collection to determine strength of relationships between image data and biophysical parameters. Timing of the data acquisition was guided of previous work by Hulsman *et al*. (1986) and Dale *et al*. (1998a) that identified critical times with respect to the tidal cycle such that standing water remains in pools after a flooding tide. Data collection proceeded after flooding tides had receded, in November 1996, as part of the PACRIM 1 project. Field data collection included vegetation structure (canopy cover, height, dbhob, density), pool locations (using GPS) depth and extent. However, difficulty in obtaining accurate GPS readings from locations within the mangroves hampered field validation processes. Night time thermal images (5m resolution) of the site, taken in August 1995 at approximately 4.00am, provided unambiguous information describing the location and perimeters of larger pools (approximately larger than 500m^2) within the mangrove forest. The locations of pool perimeters in the thermal image have previously been validated with field data.

The SAR data were ground range adjusted to a 5m by 5m resolution and georeferenced to a 1:25,000 topographic image map of the scene. A spatial subset was extracted and used to georeference the thermal images. The resulting data set consisted of 14 layers: 1 night time thermal, 1 day time thermal, 4 C-band layers, 4 L-band layers and 4 P-band layers - HH, VV, HV and Total Power layers for each band. Data analysis was undertaken using the ENVI image processing software (Research Systems Inc.) utilising standard analytical procedures and purpose built AIRSAR capabilities.

3. Results

Single-band analysis.

Each wavelength was analysed individually to determine the extent to which pools could be differentiated based on the known pool perimeters. A range direction shift effect or off-set was evident, particularly in the C- and L-band images. Consistently higher pixel intensities were found from pixels located on the far-range perimeter of pools

compared to the those pixels located on the near-range perimeter. Table 1 illustrates this pattern with typical pixel responses from the near-range perimeter, far-range perimeter and pool center for C-, L- and P-band (HH).

Table 1: Typical C-, L- and P-band HH responses showing range directional off-set for pixels on the near-range side and far-range side of a typical pool

Source data	Near-range side	Far-range side	Pool center
C-band HH	-10 to -14 dB	-5 to -8 dB	-20 to -25 dB
L-band HH	-14 to -18 dB	-10 to -13 dB	-23 to -26 dB
P-band HH	-14 to -16 dB	-14 to -19 dB	-19 to -25 dB

The proportion of "pool" designated pixels actually identified as being "pool" increased with wavelength from C-band to P-band. This was interpreted as being a response to interaction of wavelength and forest structure. Hypotheses explaining wavelength and scattering mechanism interactions with forest structure (including odd-(single) bounce, double-bounce and volume scattering) are examined below. L-band produced the most distinguishable pool delineation, however, P-band contained the highest proportion of pixels corresponding to the pool perimeters. For C-band and L-band the VV polarised data was found to give the greatest contrast between pools and surrounding forest. However, the combined Total Power image gave the best discrimination for P-band.

Multi-band Multi-layer Analysis.

Various multi-layer approaches have been taken in attempts to identify pools within the mangrove forest ustilising the multifequency and fully polarimetric characteristics in the AIRSAR data. This work is ongoing with results presented here being work in progress. Four main approaches have been taken thus far. These include unsupervised isodata classifications, ENVI AIRSAR scattering classification, textural analysis and transformations using principal components analysis. Various other image enhancing techniques such as spectral slicing, intensity stretching and image contouring have been used to interpret and evaluate results. Generally, analysis involved combining data in three stages. Firstly, each band was evaluated by including HH, VV and HV layers; secondly, all available data (C-, L- and P-band , HH, VV, HV and TP) were included; thirdly, the resultant images were combined.

Unsupervised Isodata Classification

Unsupervised isodata classification using P-band HH, HV and HV gave a better discrimination of pools than any other combination of input layers. Smaller pools were identified in a class in this classification whereas in C-band, L-band and C- + L- + P-band classifications these pools were not differentiated from the surrounding forest. The range directional off-set was still evident for larger pools, however, for the smaller pools this effect was not apparent.

ENVI AIRSAR Scattering Classification

ENVI's AIRSAR Scattering Classification routine utilises the three stokes matrix files (C-, L- and P-band) as input. A limitation of this is that the output images are in slant-range requiring transformation to match the georeferenced thermal image to evaluate its accuracy. Visual inspection suggests this classification routine could produce a useful result. Individual scattering mechanism images were also produced corresponding to odd-bounce, double-bounce and volume scattering. Analysis of these images for each band has identified more questions about the significant mechanisms affecting responses from the mangrove habitat.

For the C-band odd-bounce mechanism there appears to be an incidence angle interaction where the near-range half of the image is blank. C-band double-bounce and volume scattering contain very little information. Likewise, the L-band scattering mechanism images contain very low (<0.05) responses for all three mechanisms over the area of mangroves. This result seems unrealistic and may indicate the ENVI AIRSAR Scattering Classifier is unsuitable for the current purpose. The P-band scattering mechanism images contain relatively more information with pixel responses averaging 0.44, 0.13 and 0.07 for odd-bounce, double-bounce and volume scattering respectively for the mangrove forest region of interest. The double-bounce mechanism image does not display any obvious pattern

with respect to the mangroves. Extraction of polarisation signatures from pixels with relatively high double-bounce responses in P-band (both single and grouped pixels) did not show typical double-bounce signatures. Unexpectedly, the P-band odd-bounce image identified canopy overhang and provided clear pool boundary identification. Research into the scattering mechanisms active in the mangrove habitat is ongoing.

Texture Analysis

Textural filters producing variance and contrast images contained clear demarcations of pool perimeters. However, the results also contained the range-directional off-set described previously. For each band there is little difference between variance images from the HH, VV or HV polarisations.

Principal Components Analysis

A principal components (PC) analysis transformation of C-, L- and P-bands using HH, VV and HV polarisation layers producing three principal component bands was undertaken. The first PC band contained about 80% of the variance and represented most of what is visible when observing the input images. The second PC band contained about 15% and more closely matched pool perimeters than either PC bands one and three. Selection of pool perimeter boundaries using appropriately selected image contours highlighted comparable pool perimeters in the PC band two image and the thermal "field" image.

1. Issues yet to be resolved

During the analysis of the 1996 AIRSAR data a number of points of interest, limitations and issues have arisen in relation to the application of this data to the task of detecting and mapping of flooding under mangroves.

Resolution limitations: It is essential for this type of application that the pixel resolution be at least _ the size of the smallest pools; a resolution of 1 meter is desirable and practical.

Range direction distortions: The apparent off-set of data in the range direction as discussed above requires further investigation to be resolved.

Scattering mechanisms: As reported above, questions concerning the applicability of the AIRSAR Scattering Classifier routine included in the ENVI image processing software have been identified. Appropriate modelling and identification of scattering mechanism requires further investigation.

Mangrove habitat base data: As for scattering mechanisms, there is a corresponding need for more base data describing the hydrogeomorphic and physiognomic character of mangrove habitats and their control on SAR backscatter.

Data accessibility and usability: The AIRSAR source data in the stokes matrix format and slant range projection is challenging to integrate into an interactive analysis programme. This is because many routines (in ENVI – eg. polarimetric signature analysis and pedestal height analysis) use the "raw" stokes matrix data as input, resulting in output images that are in slant range projection and not georeferenced. However, it is essential that images be georeferenced and co-registered for accurate connection with field and other data sources.

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